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Title: A Universe of Unknowns: Dark Matter and Dark Energy

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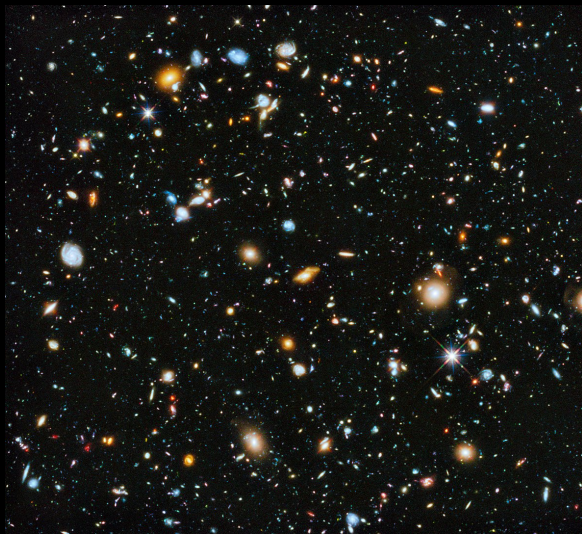
# A Universe of Unknowns: Dark Matter and Dark Energy

Jonah Miller

Los Alamos National Laboratory

Extended Learning Saturday  
Feb. 29, 202

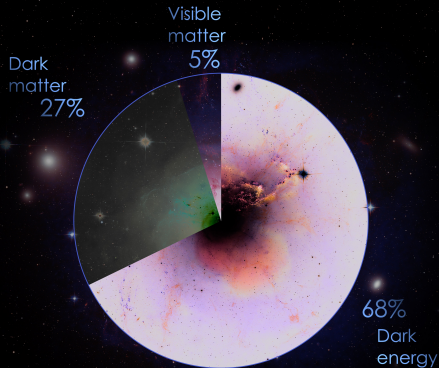
# What's Out There?



NASA/HST

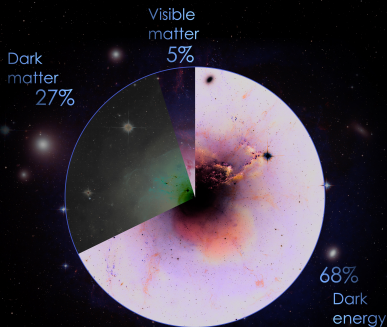


# That's only $\sim 5\%$ !



NASA/ESA/Planck

# The Big Questions



NASA/ESA/Planck

- What is it?
- How do we know?

Dark Matter

# Galaxy Rotations



Lexus

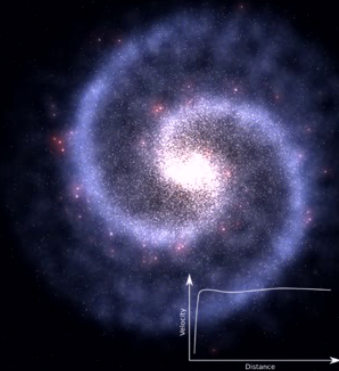


NASA/HST

# Galaxies With and Without Dark Matter

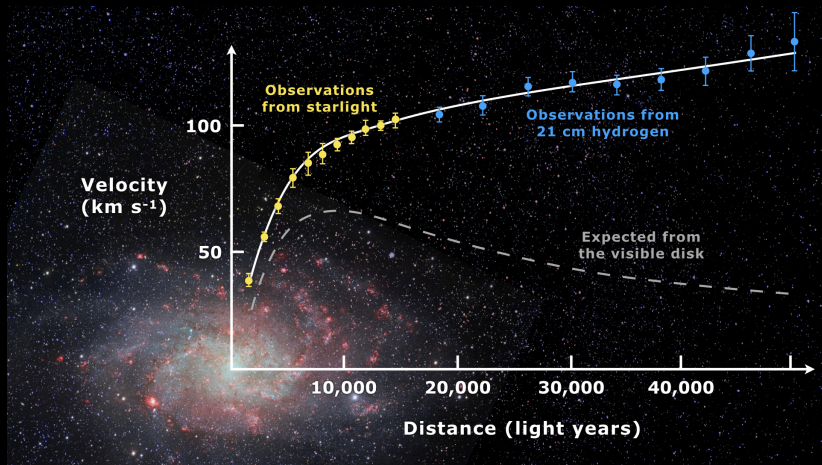
- Without dark matter

- With dark matter



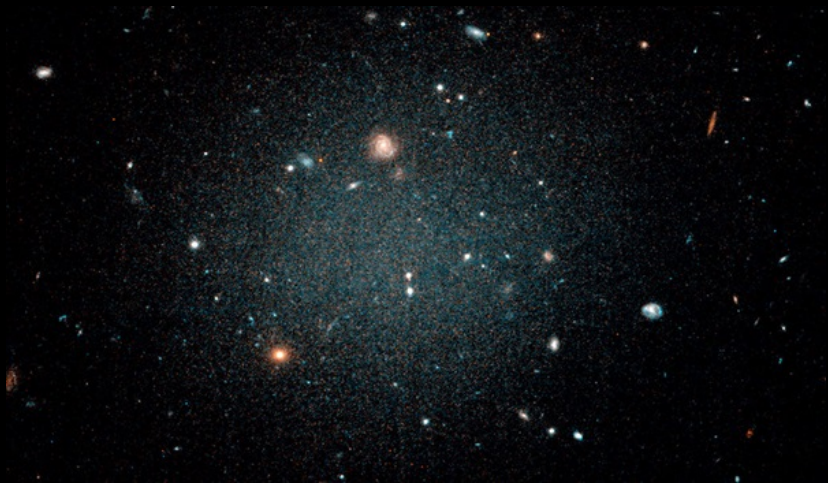
Ingo Berg

# The Rotation Curve



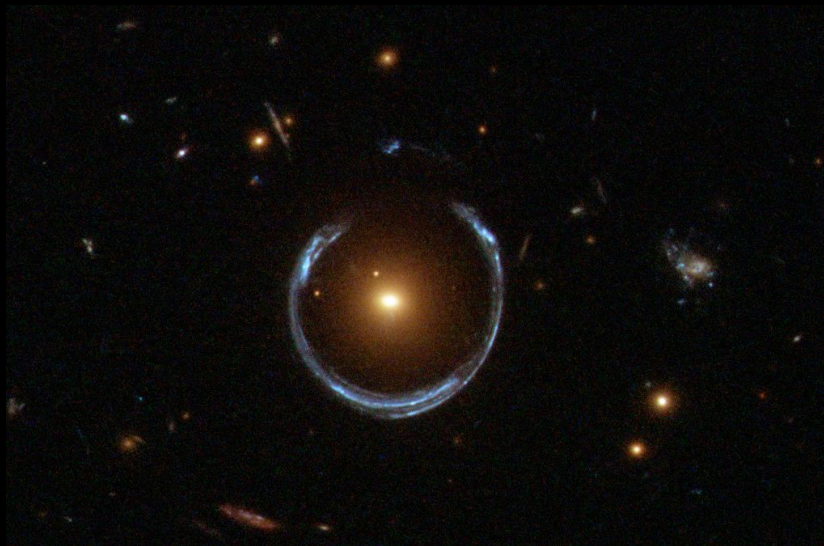
Mario de Leo

# Some Galaxies Don't Have Dark Matter!



Van Dokkum et al. *Nature* **555** 629 (2018)

# Gravitational Lensing



NASA/HST APOD

J.M.M (LANL)

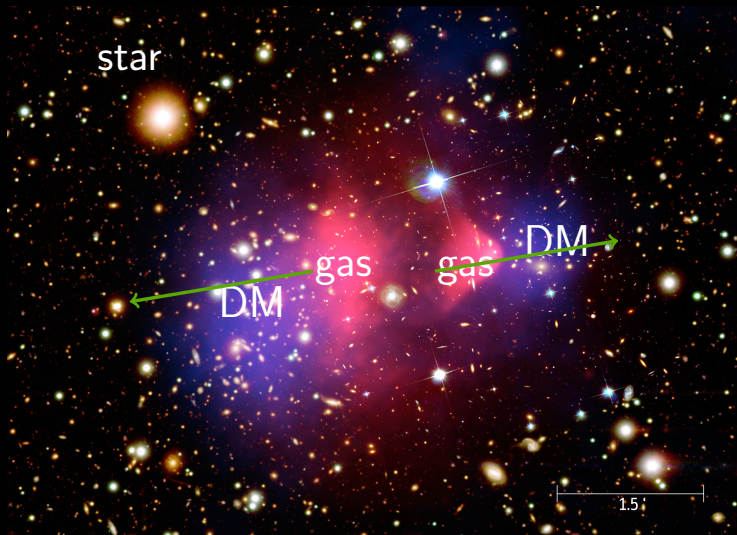
Dark Universe

Feb. 29, 2020

10 / 29

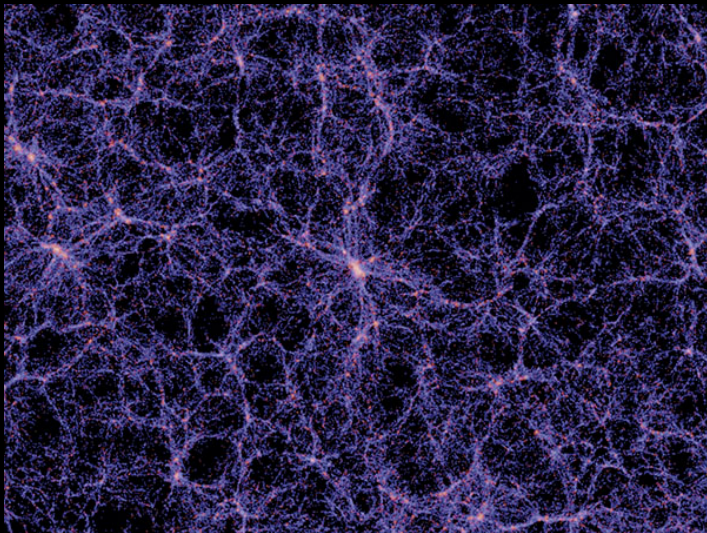


# Dark Matter Bends Light



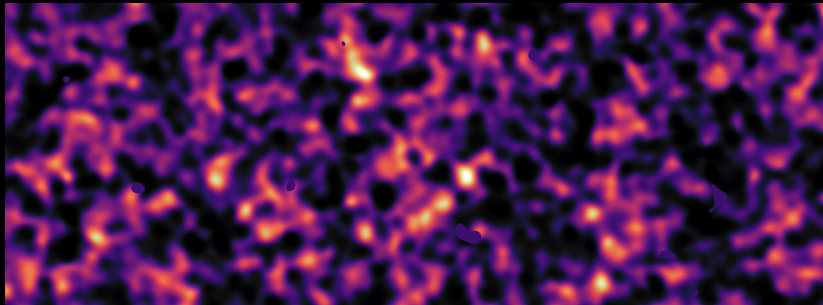
NASA/CXC/Chandra/M. Weiss

# The Cosmic Web



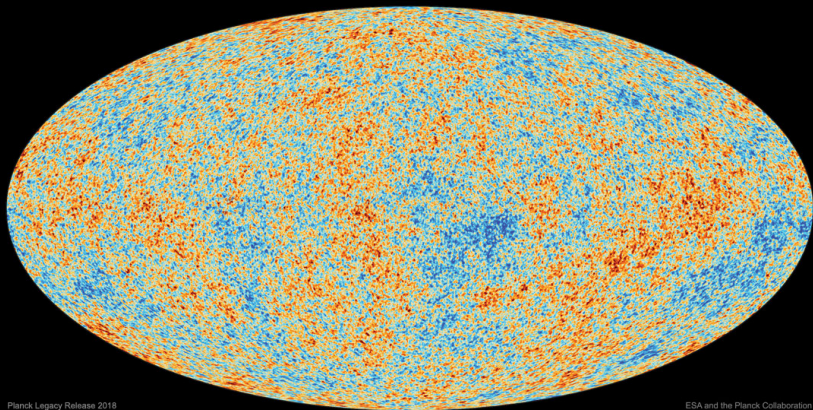
V. Springel

# The Cosmic Web in Lensing



ESA/KiDS

# The Cosmic Microwave Background



Planck Legacy Release 2018

ESA and the Planck Collaboration

ESA/Planck

# Dark Matter Summary

- It's out there
- It holds galaxies together
- We have no idea what it is!

Dark Energy

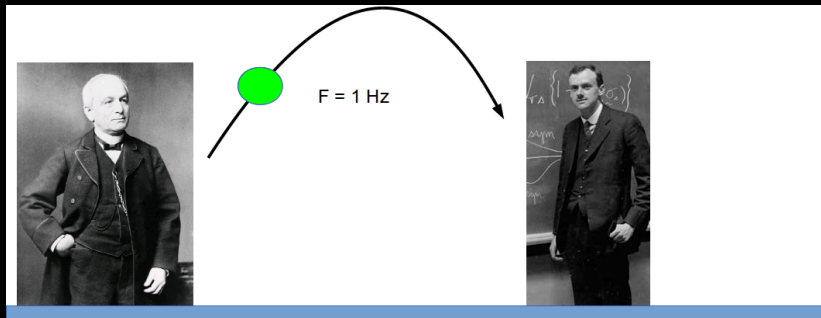
# Hubble and the Expanding Universe



Hubble at Mt. Wilson Observatory in 1937.

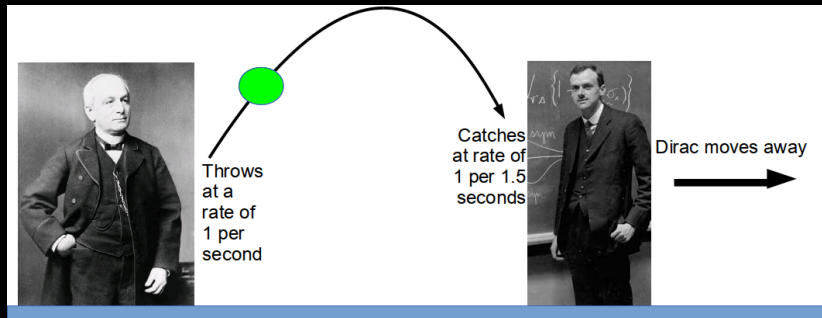
Margaret Bourke-White/Time & Life Pictures/Getty Images

# The Doppler Effect





# The Doppler Effect

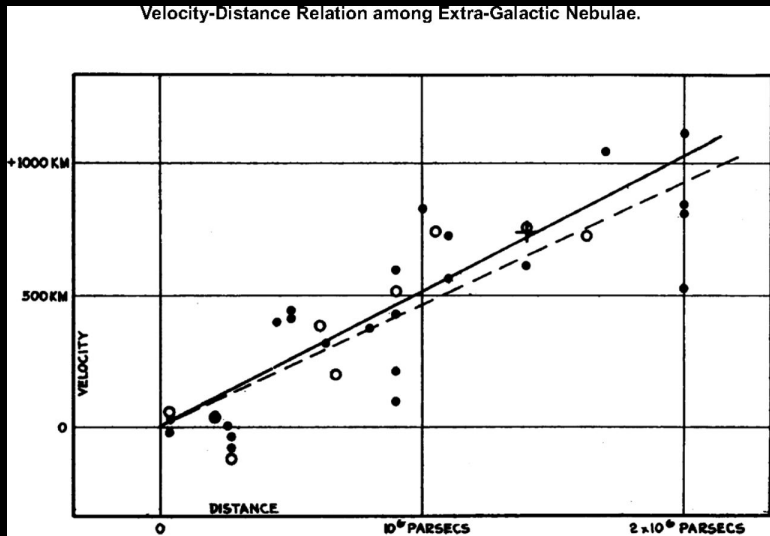


# Redshift!



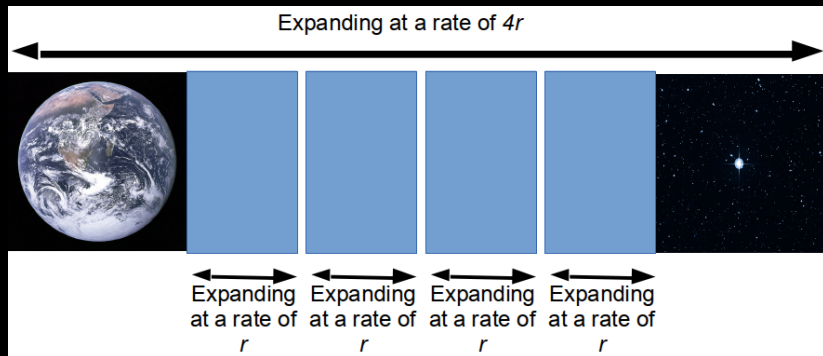
Tipping the Spherical Cow

# Hubble's Law

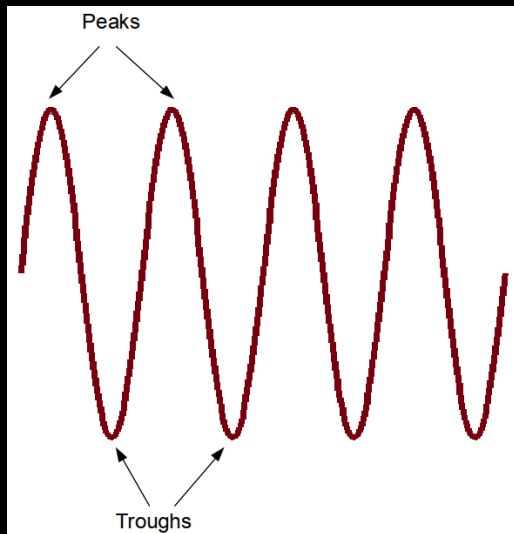


E. Hubble

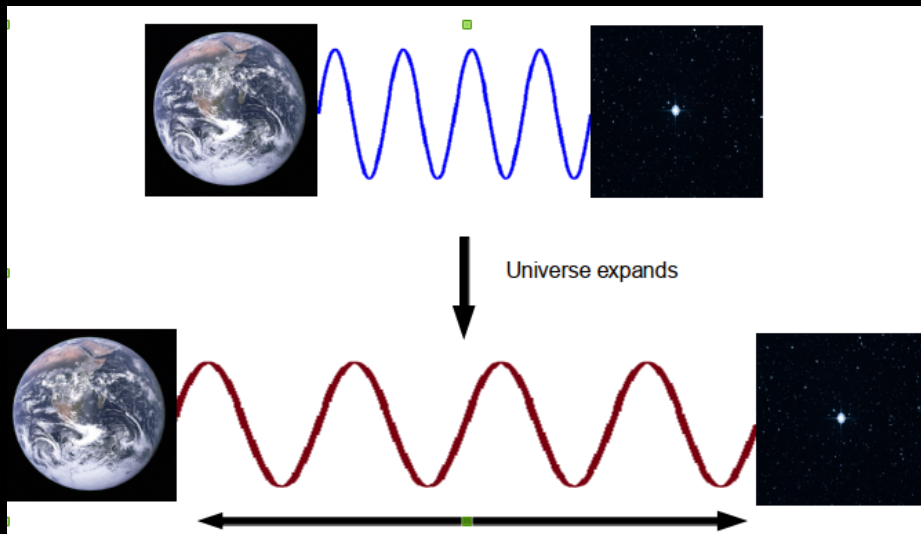
# The Universe Is Expanding!



# Seen Another Way...

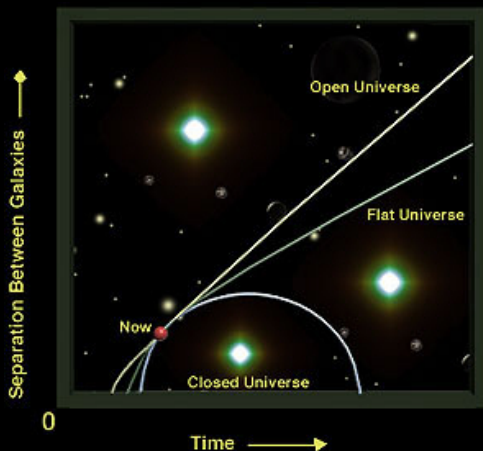


# Seen Another Way...



# As of the Early 90s...

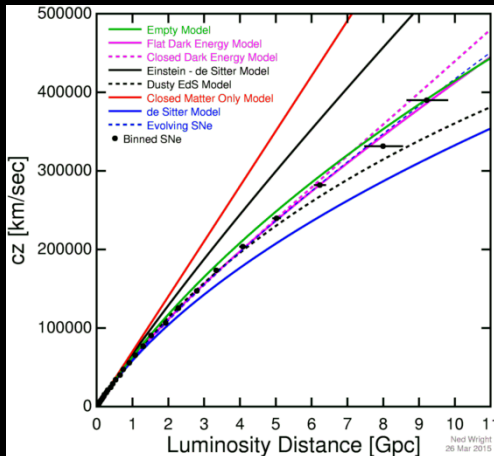
- This is wrong!



Sloan Digital Sky Survey

# Supernovae Extend the Hubble Diagram

- This is right!

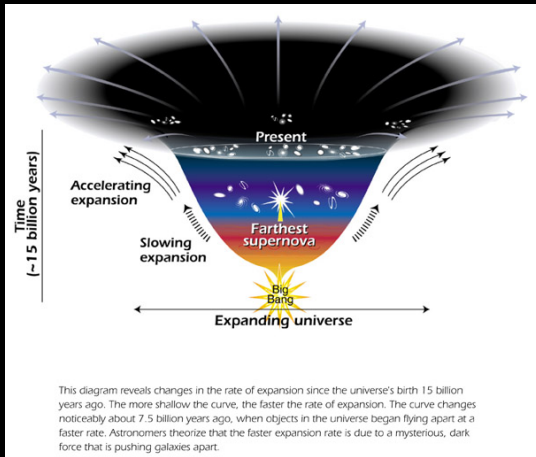


Ned Wright



# The Universe is Accelerating!

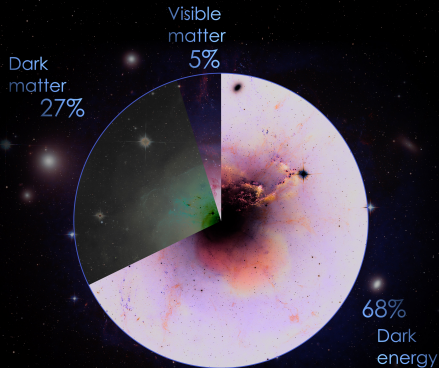
- The further away we look, the deeper into the past
- Things we moving away from each other more slowly in the past



# Dark Energy Summary

- The universe is expanding—galaxies are moving away from each other
- The rate of expansion is accelerating
- We have no idea why
- We call the cause Dark Energy
- It pushes galaxies apart

# We have no idea!



NASA/ESA/Planck